FSS Survey Series: 2009/03

Celtic Sea Herring Acoustic Survey Cruise Report 2009

Acoustic calibration at Bere Island

Ryan Saunders[1], Ciaran O'Donnell[1], Andrew Campbell[1], Deirdre Lynch[1], Kieran Lyons[2] and Dave Wall[3]

[1]The Marine Institute, Fisheries Science Services,

Rinville, Oranmore, Co. Galway.

[2]The Marine Institute, Ocean Science Services

[3] Irish Whale and Dolphin Group (IWDG)

Table of Contents

1 Introduction

In the southwest of Ireland and the Celtic Sea (ICES Divisions VIIaS, g & j), herring are an important commercial species to the pelagic and polyvalent fleet. The local fleet is composed of dry hold polyvalent vessels and a small number of purpose built Refrigerated seawater vessels (RSW). The stock is composed of both autumn and winter spawning components and the fishery targets pre-spawning and spawning aggregations. The Irish commercial fishery has historically taken place within 1-20 nmi (nautical miles) of the coast and focused on aggregated schools within the spawning cycle. In recent years the larger RSW vessels have actively targeted offshore summer feeding aggregations in the south Celtic Sea. In VIIj, the fishery traditionally begins in mid September and is concentrated within several miles of the shore including many bays and inlets. The VIIaS fishery peaks towards the year end in December, but may be active from mid October depending on location. In VIIg, along the south coast herring are targeted from October to January at a number of known spawning sites and surrounding areas. Overall, the protracted spawning period of the two components extends from October through to January, with annual variation of up to 3 weeks. Spawning occurs in successive waves in a number of well known locations including large scale grounds and small discreet spawning beds.

The stock structure and discrimination of herring in this area has been investigated recently. Hatfield et al. (2007) has shown the Celtic Sea stock to be fairly discrete. However, it is known that fish in the eastern Celtic Sea recruit from nursery areas in the Irish Sea, returning to the Celtic Sea as young adults (Brophy et al. 2002; Molloy et al., 1993). The stock identity of VIIj herring is less clear, though there is evidence that they have linkages with VIIb and VIaS (ICES, 1994; Grainger, 1978). Molloy (1968) identified possible linkages between young fish in VIIj and those of the Celtic Sea herring. For the purpose of stock assessment and management divisions VIIaS, VIIg and VII j have been combined since 1982.

For a period in the 1970s and1980s, larval surveys were conducted for herring in this area. However, since 1989, acoustic surveys have been carried out, and currently are the only tuning indices available for this stock. In the Celtic Sea and VIIj, herring acoustic surveys have been carried out since 1989, and this survey represents the 18th in the overall acoustic series or the fourth in the modified time series.

The geographical confines of the annual 21 day survey have been modified in recent years to include areas to the south of the main winter spawning grounds in an effort to identify the whereabouts of winter spawning fish before the annual inshore spawning migration. Spatial resolution of acoustic transects has been increased over the entire south coast survey area. The acoustic component of the survey has been further complimented by detailed hydrographic and marine mammal and seabird work programs first initiated during this survey in 2004.

2 Materials and Methods

2.1 Scientific Personnel

FSS	Ryan Saunders	Acoustics (SIC)
FSS	Deirdre Lynch	Acoustics
FSS	Andrew Campbell	Acoustics
FSS	Turloch Smith	Acoustics
FSS	Michael McAuliffe	Biologist
FSS	Tobi Rapp	Biologist
FSS	Kieran Mc Cann	Biologist (Deck Sci)
FSS	Clementine Harma	Biologist
IWDG	Dave Wall	Marine Mammal Obs.
SWFB	John O' Regan	Fisheries Observer

2.2 Survey Plan

2.2.1 Survey objectives

The primary survey objectives are listed below:

- Carry out a pre-determined survey cruise track
- Determine an age stratified estimate of relative abundance of herring within the survey area (ICES Divisions VIIj, VIIg and VIIaS)
- Collect biological samples from directed trawling on insonified fish echotraces to determine age structure and maturity state of the herring stock
- Collect ancillary information on secondary pelagic species such as sprat and pilchard to determine biomass and abundance within the survey area
- Collect physical oceanography data as horizontal and vertical profiles from a deployed sensor array.
- Survey by visual observations marine mammals and seabird abundance and distribution during the survey

2.2.2 Area of operation

The autumn 2009 survey covered the area from Loop Head in ICES Division VIIb (Figure 1) in Co. Clare and extended south along the western seaboard covering the main bays and inlets in Divisions VIIj & VIIg. The survey started in the north and worked in a southerly direction to facilitate temporal progression of spawning within stock components.

The survey was broken into 2 main components (Table 1). The first, a broad scale survey, was carried out to contain the stock within the survey confines and was based on the distribution of herring from previous years surveys (O'Donnell *et al.,* 2004; 2005a; 2005b; 2006; 2007; 2008). The broad scale survey was composed of 10 strata and formed an integral component of the overall survey. Broad scale outer lying areas form an important transit area for herring migrating to and from inshore spawning areas and from offshore summer feeding grounds. The second component of the survey focused exclusively on known spawning areas and was made up of 6 strata.

2.2.3 Survey design

A parallel transect design was adopted with transects running perpendicular to the coastline and lines of bathymetry, where possible, within each strata. Offshore extension reached up to 65nmi (nautical miles). Transects resolution was set at between 2 - 4nmi for the broad scale survey and increased to 1nmi for the spawning ground surveys. Bay areas were surveyed using a zigzag transect approach to maximise geographical coverage within these confined areas.

Transect start points within each stratum are randomised each year using a random number generator within established baseline stratum bounds.

In total the combined survey accounted for 3,190 nm, with around 2,700 nm of integrateable acoustic transect data collected.

2.3 Equipment and system details and specifications

2.3.1 Acoustic array

Equipment settings for the acoustic equipment were determined before the start of the survey program and were based on established settings employed by FSS on previous surveys (O'Donnell *et al.,* 2004). The settings used on the *Celtic Explorer* acoustic array are shown in Table 2.

Acoustic data were collected using the Simrad ER60 scientific echosounder. The Simrad ES-38B (38 KHz) split-beam transducer is mounted within the vessel's drop keel and lowered to the working depth of 3.3m below the vessel's hull or 8.8m below the sea surface. Three other operating frequencies were used during the survey (18, 120 and 200Khz) for trace recognition purposes, with the 38Khz data used solely to generate the abundance estimate.

Whilst on survey track the vessel is normally propelled using DC twin electric motor propulsion system with power supplied from 1 main diesel engine, so in effect providing "silent cruising" as compared to normal operations (Anon, 2002). During fishing operations normal 2 engine operations were employed to provide sufficient power to tow the net.

2.3.2 Calibration of acoustic equipment

A calibration of the ER60 was carried out behind Bere Island on the 25th of October. The calibration report for the 38 kHz transducer is included in Annex 1. The calibration was conducted in 30 m of water during the evening and night time. Night-time calibrations are considered to be robust, particularly when extra data points are collected for the beam model and S_a correction calculations. Over 350 data points were collected at each frequency, so the potential impact of DVM organisms distorting the calibration is highly unlikely. Indeed, the calibration experiment gave good results for the 38 kHz transducer. However, the ER60 was not updated using the 2009 calibration experiment results. The ER60 was last calibrated in Irish coastal waters 7 months prior to the survey start (O'Donnell *et al,* 2009) and these settings remain the same.

2.4 Survey protocols

2.4.1 Acoustic data acquisition

Acoustic data were observed and recorded onto the hard-drive of the processing unit using the equipment settings from previous surveys (Table 2). The "RAW files" were logged via a continuous Ethernet connection as "EK5" files to the vessels server and the ER60 hard drive as a backup in the event of data loss. In addition, as a further back up a hard copy was stored on DVD. Sonar Data's Echoview® Echolog (Version 4) live viewer was used to display the echogram during data collection to allow the scientists to scroll through echograms noting the locations and depths of fish shoals. A member of the scientific crew monitored the equipment continually. Time and location (GPS position) data was recorded for each transect within each strata. This log was used to monitor the time spent off track during fishing operations and hydrographic stations plus any other important observations.

2.4.2 Echogram scrutinisation

Acoustic data was backed up every 24 hrs and scrutinised using Sonar data's Echoview® (V 4) post processing software. Partitioning of data into the categories shown below was largely subjective and was viewed by a scientist experienced in viewing echograms.

The NASC (Nautical Area Scattering Coefficient) values from each herring region were allocated to one of 4 categories after inspection of the echograms. Categories identified on the basis of trace recognition were as follows:

1. "Definitely herring" echo-traces or traces were identified on the basis of captures of herring from the fishing trawls which had sampled the echo-traces directly, and on large marks which had the characteristics of "definite" herring traces (i.e. very high intensity (red), narrow inverted tear-shaped marks either directly on the bottom or in mid-water and in the case of spawning shoals very dense aggregations in close proximity to the seabed).

2. "Probably herring" were attributed to smaller echo-traces that had not been fished but which had the characteristic of "definite" herring traces.

3. "Herring in a mixture" were attributed to NASC values arising from all fish traces in which herring were thought to be contained, owing to the presence of a proportion of herring within the nearest trawl haul or within a haul that had been carried out on similar echo-traces in similar water depths.

4. "Possibly herring" were attributed to small echo-traces outside areas where fishing was carried out, but which had the characteristics of definite herring traces.

The "EK5" files were imported into Echoview for post-processing. The echograms were divided into transects. Echo integration was performed on a region which were defined by enclosing selecting marks or scatter that belonged to one of the four categories above. The echograms were analysed at a threshold of -70 dB and where necessary plankton was filtered out by thresholding at –65 dB.

The allocated echo integrator counts (NASC values) from these categories were used to estimate the herring numbers according to the method of Dalen and Nakken (1983).

The TS/length relationships used were those recommended by the acoustic survey planning group (Anon, 1994) and were as follows:

Herring	TS = 20logL – 71.2 dB per individual (L = length in cm)
Sprat	TS = 20logL – 71.2 dB per individual (L = length in cm)
Mackerel	TS = 20logL – 84.9 dB per individual (L = length in cm)
Horse mackerel	TS = 20logL – 67.5 dB per individual (L = length in cm)

The TS length relationship used for gadoids was a general physoclist relationship (Foote, 1987):

Gadoids	TS = 20logL – 67.5 dB per individual (L = length in cm)

2.4.3 Biological sampling

A single pelagic midwater trawl with the dimensions of 19m in length (LOA) and 6m at the wing ends and a fishing circle of 330 m was employed during the survey (Figure 22). Mesh size in the wings was 3.3 m through to 5 cm in the cod-end. The net was fished with a vertical mouth opening of approximately 9 m, which was observed using a cable linked "BEL Reeson" netsonde (50 kHz). The net was also fitted with a Scanmar depth sensor. Spread between the trawl doors was monitored using Scanmar distance sensors, all sensors being configured and viewed through a Scanmar Scanbas system.

All components of the catch from the trawl hauls were sorted and weighed; fish and other taxa were identified to species level. Fish samples were divided into species composition by weight. Species other than the herring were weighed as a component of the catch. Length frequency and length weight data were collected for each component of the catch. Length measurements of herring, sprat and pilchard were taken to the nearest 0.5 cm below. Age, length, weight, sex and maturity data were recorded for individual herring within a random 50 fish sample from each trawl haul, where possible. All herring were aged onboard. The appropriate raising factors were calculated and applied to provide length frequency compositions for the bulk of each haul.

Decisions to fish on particular echo-traces were largely subjective and an attempt was made to target marks in all areas of concentration not just high density shoals. No bottom trawl gear was used during this survey. However, the small size of the midwater gear used and its manoeuvrability in relation to the vessel power allowed samples at or below 1m from the bottom to be taken in areas of clean ground.

2.4.4 Oceanographic data collection

Oceanographic stations were carried out during the survey at predetermined locations along the track. Data on temperature, depth and salinity were collected using a Seabird 911 sampler at 1m subsurface and 3m above the seabed. Coverage was broken down into 4 main hydrographic transects with CTD casts undertaken on selected transects in each of the target strata. Hydrographic stations were equally spread at 6-10nmi spacing on each transect where possible (Figure 9).

2.4.5 Marine mammal and seabird observations

During the survey an observer kept a daylight watch on marine mammal and seabird sightings from the crow's nest (18m above sea level).

During cetacean observations, watch effort was focused on an area dead ahead of the vessel and 45^{o} to either side using a transect approach. Sightings in an area up to 90^{o} either side of the vessel were recorded. The area was constantly scanned during these hours by eye and with binoculars. Ship's position, course and speed were recorded, environmental conditions were recorded every 15 minutes and included, sea state, visibility, cloud cover, swell height, precipitation, wind speed and wind direction. For each sighting the following data were recorded: time, location, species, distance, Bereing and number of animals (adults, juveniles and calves) and behaviour. Relative abundance (RA) of cetaceans was calculated in terms of number of animals sighted per hour surveyed (aph). RA calculations for porpoise, dolphin species and minke whales were made using data collected in ≤ Beaufort sea state 3. RA calculations for large whale species were made using data collected in ≤ Beaufort Sea state 5.

2.5 Analysis methods

2.5.1 Echogram partitioning

The analysis produced density values of numbers and biomass per nautical mile squared for each transect and mark category for each target species. These were then averaged over each stratum (weighted by transect length) and a biomass and abundance estimated by applying the stratum area and summing the strata estimates. Note that interconnecting inshore and offshore inter-transects were not included in the analysis. Total estimates and age and maturity breakdowns were calculated. Coefficient of variation (cv, standard error divided by the estimate) was estimated in the usual way after assuming that transects were identically distributed within a stratum and that they were statistically independent. CV were not reported for quantities that were unlikely to be used in a stock assessment (e.g., biomass of spent fish).

Biomass was calculated from numbers using length-weight relationships determined from the trawl samples taken during the survey for each of the analysis areas.

Herring weight (grams) = 0.00648* $L^{3.351}$ (L = length in cm)

Mackerel weight (grams) = 0.01118* $L^{3.032}$ (L = length in cm)

Sprat weight (grams) = 0.02404* $L^{3.192}$ (L = length in cm)

2.5.2 Abundance estimate

Total abundance, N_T, is given by $\sum_{m}^{Mark-types} N_{T,m}$, the sum over the total abundance by mark-types.

$$N_{T,m} = \sum_{s}^{strata} N_{m,s}$$

Suppressing the mark-type index, m, the stratum abundance is

$$N_s = area_s \sum_{l}^{transects} \overline{n}_{s,t} l_{s,t} \Big/ \sum_j l_{s,j}$$

,where *l* is the transect length and $\overline{n}$ is the transect mean abundance n.mi^{-2} which is given by

$$\sum_{j}^{track\cdot fragments} n_{s,t,j} d_{s,t,j} \Big/ l_{s,t}$$

, where d is the distance of the track fragment and $n_{s,t,j}$ is the mean abundance n.mi^{-2} for the jth track fragment.

Hauls are assigned with there own stratification that may not necessarily coincide with the acoustic strata, the conversion of NASC into mean density is done at the track fragment level, usually a 1 n.mi segment. The haul assigned, $h_{m,s,t,j}$, depends strongly on the mark-type (m) and since more than one school can be in a track fragment it needs to be specified. Since age and maturity length-keys are to be applied, the basic estimation is mean density by length bins. The $n_{s,t,j}$ is found by summing over the $n_{s,t,j}$.

$$n_{t,j,i} = \frac{NASC_{t,j}}{\overline{\sigma}_{h_{m,t,j}}} p_{i,h_{m,t,j}}$$

, where *i* indexes length bins, p_i is the proportion of herring in the i^{th} length bin, and is given by $\sum_{spe}^{species} \sum_{i} p_{spe,i} 10^{(a+b\log 10(L_{spe,i}))/10}$

, where $p_{spe,i}$ applies over all species considered in the haul, $L_{spe,i}$ is the length to use for the i^{th} length bin and the data comes from the haul (of combination of hauls) assigned, $h_{m,t,j}$. For non-mix mark-types, the later simplifies to

$$\sum_{i} p_{herring,i} 10^{(073+20\log 10(L_{herring,i}))/10}.$$

For biomass, a mean weight is also applied to the $n_{t,j,i}$ using the estimated regression relationship, a L_i^b.

For abundance by age and maturity, the abundance by length bin, $n_{t,j,i}$, is averaged over track fragments and then transects to give a strata (and mark-type) mean. The age and maturity keys are applied to the results.

$V_s = area_s^2 s_s^2 W_s$, where $W_s = \sum_{l}^{transects} l^2_{s,t} \Big/ (\sum_{j} l_{s,j})^2$ and s^2 is the sample variance. The variance for the total is the sum of strata variances.

The total biomass can be obtained directly from the track fragment mean biomass by $B_T = \sum_{k}^{track \cdot fragment} \bar{n}_k w_k$, where w_k is a factor that takes into account the factors for transect and strata averaging, i.e., $w_k = \frac{1n.mi}{l_{t_k}} \frac{l_{t_k}}{\sum_{t}^{stratum.s_k} l_{s_k,t}} area_{s_k} = \frac{1}{\sum_{t}^{stratum.s_k} l_{s_k,t}} area_{s_k}$

, where the 1 n.mi is the length of the track fragment. This ignores the mark-type since that is already accounted for in the $\bar{n}_k$. The $\bar{n}_k w_k$ is the biomass from a track fragment and they can then be used to map the biomass at a fine spatial scale.

Estimates are made for SSB, total abundance and biomass, abundance by age (ring counts), and abundance by age x length bins. A cv (based on strata standard error divided by the strata mean) is estimated for SSB, total abundance and biomass, and abundance by age.

3 Results

3.1 Celtic Sea herring stock

3.1.1 Herring biomass and abundance

Herring	Millions	Biomass (t)	% contribution
Total estimate			
Definitely	828	91,764	77.1
Mixture	220	14,000	11.8
Probably	99	13,319	11.2
Total estimate	1147	119,083	100
SSB Estimate			
Definitely	512	75,071	82.6
Probably	78	11,594	12.7
Mixture	46	4,272	4.7
SSB estimate	636	90,937	100

Estimates of herring biomass and abundance detected during the survey are summarised above. These estimates were derived from 644 echotraces that were identified with the aid of 30 directed net hauls (Figure 2). Of the total number of echotraces attributed to herring, approximately 44% were in the 'Definitely herring' category, 47% were classed as 'Mixed herring' and 9% occurred in the 'Probably herring' category (Table 11).

The overall herring biomass and abundance estimates were approximately 119,000 t (CV 22.7%) and 1147 million individuals (CV 23.1%), respectively. The overall SSB observed during the survey was almost 91, 000 t (CV 24%), comprising an abundance of this component in the order of 636 million individuals. These estimates of abundance and biomass constitute the highest detected in the region during the c. 10 year acoustic survey time-series. However, the total SSB estimate is similar to that observed in 2008. The majority of herring biomass detected throughout the survey occurred in discrete schools that were classified as 'Definitely herring' according to targeted net hauls (77% and 83% for TSB and SSB, respectively). However, a substantial proportion of herring TSB occurred in mixed species assemblages (c. 12%), and the 'Probably herring' category comprised around 12% of both the TSB and SSB estimates. Estimates from these categories are still considered to be robust due to the high frequency of net sampling conducted throughout the survey region.

Herring stock abundance and biomass estimates are further broken down by age, maturity status, size and strata in Tables 6-10. The length frequency data used to calculate herring target strength for the TSB and SSB estimates are presented in Table 4, and herring school counts by category and strata are presented in Table 11. In general, the majority of herring biomass and abundance occurred in 4 strata (strata 8, 9, 10 and 12), with stratum 12 and stratum 9 contributing the greatest proportions to the TSB and SSB estimates. Of the 19 strata surveyed, 12 contained no herring. Herring within the 3 winter-ring group had the highest biomass (c. 32,000 t; Table 6), although the 0 and 1 winter-ring group comprised the greatest abundance (239 million and 381 million individuals, respectively; Table 7). Around 24% of the total herring biomass detect during the survey was derived from the juvenile component of the population (Table 8). This contrasts markedly with the 2008 survey where the juvenile proportion represented just 3% of the TSB.

3.1.2 Herring distribution

A total of 30 trawl hauls were carried out during the survey (Figure 2), with 23 hauls containing herring and 11 hauls containing >50% herring by weight of bulk catch (Table 3). In general, large and dense herring schools were predominantly distributed close inshore around a single spawning ground in the Tramore Bay region (stratum 12: Figure 3). Relatively large herring schools were also detected in more offshore regions to the north of the Rigs and towards the most south-easterly sector of the survey grid. Most herring schools were detected between 7-8 ºW, although several occurred in the region to the north of Fastnet Island and a few were situated around c. 10 nm southwest of Ballycotton.

The majority of discrete herring schools detected throughout the survey were positioned in close proximity to the sea-bed, or occurred as dense 'towers' protruding from the sea-bed. Mixed species assemblages that often contained around 20% herring (usually as intense 'chips') were also distributed in regions close the bottom. Only a few herring schools were distributed between the surface and mid-water depth. No herring were found in the southwest region of the survey area, except for a relatively small proportion observed in Dingle Bay. Overall, our observations accord well with reports from the commercial fishing fleet operating in the region in that substantial catches of herring were obtained by the fleet in regions around Fastnet, Mine Head and in close proximity to Tramore Bay.

3.1.3 Herring stock composition

A total of 1,012 herring were aged during the survey. Also, over 5,120 herring were measured and approximately 2,740 length-weight measurements were obtained (Tables 3, 4 & 5). Herring age samples predominantly ranged from 1-5 winter-rings (Tables 6 & 7). The dominant age groups in terms of biomass were the 3 and 1 winter-ring fish that accounted for around 27% of the total TSB per group (32,000 t and 31,000 t, respectively). The 5 winter-ring group was also relatively strong comprising about 18% of the TSB (c. 22,000 t). Accordingly, these 3 cohorts were strong in terms of numerical abundance (3-group= 124.6 million, CV 24.6%; 1-group= 381.4 million, CV 41.5%; 5-

goup= 124.6 million, CV 26.3%). The population also contained a relatively high abundance of small herring (mean length: 15.4 cm) within the 0 winter-ring group (239.5 million, CV 47.2%) that comprised approximately 21% of the TSN, but just 5.4% of the TSB. The majority of the 0-group was distributed in the offshore sector of the survey grid (stratum 9), with relatively few present as far inshore as the spawning bays. Herring maturity, as determined from trawl samples, showed the majority of the stock to be either in a pre-spawning state or immature. No spawning individuals and no spent fish were encountered during the survey (Tables 8 & 9).

The whole mature component of the herring stock (stages 3 to 9) sampled during the survey was in a pre-spawning state and was predominantly comprised of stage 4 individuals (70% of the mature component). This is similar to that observed in 2008 and 2007.

3.2 Secondary pelagic species

During the scrutinisation process, acoustic data were categorised for secondary and tertiary target species (see section 2.4.2) based on information from trawl data. Sprat and Mackerel (*Scomber scrombrus*) were encountered regularly during the survey. Mackerel occurred in several of the nets, but generally only in low proportions. Of the 30 net hauls deployed, only 3 contained proportions of mackerel >40% by weight of bulk catch (Table 3). Mackerel catches were dominated by juveniles. The amount of single mackerel schools observed was low (Figure 6), with the majority occurring as mixed schools. There were generally fewer observations of mackerel on this survey than during the survey conducted in 2008. Due to insufficient net haul data on mackerel, the scrutinisation of the species cannot be considered robust and no biomass was determined for mackerel.

The distribution and abundance of horse mackerel (*Trachurus trachurus*) schools in the southwest area were notably scare during the 2008 survey compared to the 2007, and as a result no biomass estimates were determined. The results of this survey are similar to those in 2008; there was very little horse mackerel present throughout the survey area. Also, there were no boarfish present during the 2009 survey, unlike in 2008.

3.2.1 Sprat abundance and biomass

Sprat	Millions	Biomass (t)	% contribution
Total estimate			
Definitely	497	4,530	27.9
Mixture	921	11,699	72.1
Probably	0	0	0.0
Total estimate	1418	16,229	100

Sprat was encountered regularly in most areas and was present in relatively high proportions in many of the net hauls (Table 3). Sprat was often difficult to differentiate from herring acoustically, so frequent net hauls were deployed on almost every target of significant size and intensity. In general, most of the sprat was distributed around mid-water column depth and was at times highly motile and difficult to catch, particularly during the daytime. These observations were also reported by the commercial fishing fleet operating in the same areas during the survey. Our net data also showed that sprat frequently occurred in mixed assemblages, often co-occurring with juvenile herring of a similar body size (Table 3). However, there was sufficient net haul data obtained at an adequate spatial resolution to enable a fairly robust categorisation of the species abundance and biomass (summarized above). The total biomass estimate for sprat was 16, 229 t (CV 31%) and the total numerical abundance was 1418 million individuals (CV 29%).

Sprat distribution is presented in Figure 4 for the “Definitely” and “Probably Sprat” category but does not include the “Sprat in a mix” which accounted for the majority of the total biomass detected (72%). Abundance and biomass by stratum are presented in Table 13. In general, more sprat was detected on the survey than during the 2008 survey. The species was widely distributed throughout the survey region with dense schools situated in close proximity to Dingle Bay, the area southeast of Ballycotton, and the most south-easterly region of the survey grid. Several mixed schools comprising sprat were detected inside Dingle Bay. The size distribution of sprat was small, ranging between 7-15 cm in length and 2-28 g in weight. The mean length was 11 cm (SD 1.6) and the mean weight was 12 g (SD 5.7).

3.3 Oceanography

A total of 53 hydrographic stations were carried out during the survey. Surface plots of temperature and salinity are presented for the 5, 20, 40 and the >60 m depth profiles in Figures 5-8. In general, the Celtic Sea area was warmer and more saline than in 2008. Temperature in the surface layers (above 5 m) was around 14-15 °C with surface salinity ranging between 34.8-35.0 ppt. Surface waters around the main spawning bays and southern coast regions were generally fresher than the off-shore sectors (Figure 5 and Figure 9). However, there was no influx of cold and saline water around the Waterford coastal region similar to that detected in 2008 and 2007. The water column below 5 m was relatively well mixed in the eastern sector of the Celtic Sea and along the southern coastal regions (14-15 °C, c. 38.8 ppt), but well stratified further offshore and towards the west (<11 °C and >35.0 ppt below 5 m). This is in contrast to 2008 where the eastern regions were more notably stratified and the coastal waters were generally colder. The impact of this on the underlying circulation pattern in the region is not clear from the data.

3.4 Marine mammal and seabird observations

Environmental data was collected at 462 stations. Sea state was ≤ 3 at 52.6% of environmental stations and ≤ 4 at 80.3% of stations. Visibility was >5km at 90% of stations, 1–5km at 15.6% of stations and <1km at 3.5% of stations. Swell of 2m+ was recorded at 4.1% of stations. Rainfall was recorded at 7.8% of stations and fog was recorded at 10.6% of stations. Two half-days and two full days of survey effort were lost due to due to bad weather (gales or dense fog). One day of survey effort was lost when the vessel went to anchor at Lawrence's Cove, Bere Island to conduct calibration of acoustic survey equipment.

3.4.1 Marine mammal sightings

91.1 hours of survey time were logged with 46.6% (42.47 hrs) of this at Beaufort sea state three or less; 73% (66.47 hrs) at Beaufort sea state four or less and 88.6% (80.61hrs) at Beaufort sea state five or less. 74 sightings of four cetacean species, totalling 1,011 individuals were recorded (Figures 10 and 11).

Identified cetacean species were fin whale (*Balaenoptera physalus*), minke whale (*Balaenoptera acutorostrata*), Risso's dolphin (*Grampus griseus*) and common dolphin (*Delphinus delphis*). All sightings of unidentified dolphins were though to be common dolphins, while all sightings of unidentified whale blows were thought to be of fin whales but were classed as fin/blue/sei according to the IWDG's cetacean sightings database classification scheme (IWDG 2009).

Common dolphins were the most commonly encountered and abundant species recorded during the survey (Table 14). Minke whales were the most commonly encountered and abundant whale species.

Identified small-toothed cetacean species were common dolphin (*Delphinus delphis*) and harbour porpoise (*Phocoena phocoena*). The distribution of dolphins and porpoise is similar to that recorded in previous years.

Most of the recorded minke whale and fin whale activity took place around Dingle Bay and Southeast of Ram Head. It is thought that the whales were feeding on sprat, mackerel and young herring at both these locations. These observed distributions match those reported on the 2008 survey closely.

3.4.2 Seabird sightings

Daily species lists were made of all seabird species seen around the survey vessel. 17 seabird species were recorded during the survey (table 3): puffin (*Fratercula arctica*); guillemot (*Uria aalge*); razorbill (*Alca torda*); gannet (*Morus bassanus*); fulmar (*Fulmarus glacialis*); great shearwater (*Puffinus gravis*), manx shearwater (*Puffinus puffinus*);

sooty shearwater (*Puffinus griseus*); kittiwake (*Rissa tridactyla*); lesser black backed gull (*Larus fuscus*); great black-backed gull (*Larus marinus*); herring gull (*Larus argentatus*); great skua (*Stercorarius skua*); parasitic skua (*Stercorarius parasiticus*); storm petrel (*Hydrobates pelagicus*); common scoter (*Melanitta nigra*) and shag (*Phalacrocorax aristotelis*).

4 Discussion and Conclusions

4.1 Discussion

The aims and objectives of the survey were carried out as planned. Weather conditions were favourable throughout the survey and all strata were sampled effectively. Extensive net sampling was conducted on almost every significant acoustic target detected, regardless of subjective mark-type classification. Furthermore, net sampling was conducted on medium-intensity layers (often containing high-intensity 'chips') that were detected continuously for >8 nm. We can therefore hold a high degree of confidence in the echotrace scrutinization for herring, and the overall results are highly robust in the context of the acoustic survey. Only 6 of the scheduled 59 CTD cast were lost due to poor weather, and the acoustic calibration was performed in favourable conditions at Bere Island.

The 2009 estimate of herring biomass is around 28, 000 t greater than that observed during the 2008 survey. The estimate is also the highest observed in the Celtic Sea area during the c. 10 year acoustic survey time-series. The results presented here corroborate the high biomass observed during the 2008 survey (c. 91, 000 t), and suggest that there has been an increase in herring stocks in the Celtic Sea over the last few years. For example, this is the forth consecutive year that the acoustic estimate has increased substantially (2005-2009). Throughout the species distributional range in the northeast Atlantic, herring stocks are generally considered to be in a state of decline with little signs of recovery in recent years. Our acoustic estimates suggest that the Celtic Sea herring stock might be countering this trend and that there is a tendency towards a recovery in the overall stock, with several strong year classes now present.

Further indication of a possible recovery in the Celtic Sea herring is that it is now becoming increasingly possible to track herring cohorts through time, and there appears to be a general tendency towards older fish becoming more prominent within the population. For example, the strong 3 and 5 winter-ring cohorts (2005 and 2003 year classes, respectively) detected during previous surveys also appears strong in the 2009 survey, indicating positive recruitment. Strong year classes were also spawned in 2007 and 2008 and are now becoming evident in the population as the abundant 1-winter-ring and 0-winter-ring groups. These preliminary trends in stock recovery are particularly interesting considering that herring are thought to be on the southern-most margins of its distributional limit in the Celtic Sea. However, herring distribution of abundance and population dynamics are highly variable in space and time, and further data are required to substantiate preliminary trends in stock recovery, and to address any potential causal mechanisms.

The distribution of herring was different to that observed in previous surveys in that the majority of herring biomass was not widely distributed and occurred predominantly within one spawning area around Tramore Bay. Our observations of herring distribution matched those of the commercial fishing fleet in the region during the survey. Furthermore, the fishing fleet similarly considered there to be an unusually high amount of herring present in the area. Communications with the fishing fleet were aided greatly by the presence of an onboard observer representing the Irish South and West Fish Producers Organisation. Throughout the survey, all herring assemblages were detected well within the confines of the survey boundaries. There were no instances of large herring schools occurring on the fringes of the survey grid. Furthermore, all the major herring cohorts were picked up in the biological samples collected on the survey. It is therefore becoming increasing apparent that the Celtic Sea Herring Acoustic Survey design is rigorous, particularly in the southwest region that constitutes the main survey sector. However, further attention should be placed on the SE corner of the grid. Historic information shows that herring are present in the Smalls area (Burd and Bracken, 1965) and future surveys should investigate this area. Standardised survey grid and fixed sampling times are essential prerequisites for quantifying inter-annual variations in herring abundance and population dynamics.

The presence of herring on the main autumn spawning grounds can extend for up to 3 months and overlaps with the arrival of the smaller winter spawning component. During this time biomass on the spawning grounds is replenished by several waves of migration. The survey is designed to contain the stock within its boundaries. As a result the 2009 biomass is likely to contain an un-quantified proportion of the winter spawning component. As no survey is currently undertaken on the winter stock component, it is impossible to determine the contribution of each component between years.

The hydrographic conditions encountered during this year's survey show the Celtic Sea to be warmer and less fresh than in 2008 and 2007. Overall, the trend in mean annual temperature in the Celtic Sea is increasing. A preliminary look at sea surface temperature in October across years (1998-2008) shows no correlation between cooler years and increased biomass. Herring are known to use temperature as one of the cues for the onset of spawning migrations. However, there are likely to be a number of complex physical and biological factors controlling such behavior and temperature alone cannot be used to model herring abundance accurately.

4.2 Conclusions

- A high quantity of herring was observed in the Celtic Sea area during the 2009 acoustic survey. The TSB, TSN and SSB was 119,083 t (CV 22.7%), 1147 million individuals (CV 23.1%) and 90, 937 t (CV 24%), respectively. The TSB is the highest observed to date.
- Standardized survey design and fixed sampling times are enabling herring cohorts to be tracked. The herring population was sampled effectively during

the survey and there is some evidence of successful recruitment of the 2007 and 2005 year classes.

- The largest herring schools were predominantly distributed inshore around the Tramore Bay spawning area. However, almost all mature fish were in a pre-spawning state (stage 4 and 5) and there were no spent individuals.

- The most widely encountered secondary species was sprat, comprising a biomass of approximately 16, 229 t (CV 31%) and a total numerical abundance of around 1418 million individuals (CV 29%).

Acknowledgements

We would like to thank Dennis Rowan (Captain) and the crew of the Celtic Explorer for their help and professionalism during the survey. We also thank John O' Regan for his expert advice on fishing operations and for liaising with the commercial fishing fleet, Clementine Harma and Michael McAullife for their meticulous quality control of biological data, and the S&SW Fisheries Organisation for providing regular information on fishing gear locations in the survey region.

References\Bibliography

Anon. (1994). Report of the planning group for herring surveys. *ICES C.M. 1994/H:3*

Anon (2002) Underwater noise of research vessels. Review and recommendations. 2002. ICES No. 209

Brophy, D., and B. S. Danilowicz. 2002. Tracing populations of Atlantic herring (*Clupea harengus* L.) in the Irish and Celtic seas using otolith microstructure. ICES Journal of Marine Science, 59:1305-1313.

Burd, A. C., and J. Bracken. 1965. Studies on the Dunmore East Herring Stock. 1. A population assessment. J.Cons.Perm. Int. Explor. Mer, 29: 277-301.

Dalen, J. and Nakken, O. (1983) "On the application of the echo integration method" ICES CM 1983/B:19

Foote, K.G. (1987). Fish target strengths for use in echo integrator surveys. *J. Acoust. Soc. Am.* 82: 981-987

Foote, K.G., Knudsen, H.P., Vestnes, G., MacLennan, D.N. and Simmonds, E.J. (1987). Calibration of acoustic instruments for fish density estimation: a practical guide. *Int. Coun. Explor. Sea. Coop. Res. Rep.* 144: 57 pp

Grainger, R. J. (1978). A study of herring stocks west of Ireland and their oceanograo-hic conditions. Oceanography. Galway, University College Galway: 262.

Hatfield, E.M.C, Zuur, A.F., Boyd, J., Campbell, N., Chubb, J., Collins, C.M.,Coughlan, J., Cross, M., Cross, T.F., Cunningham, C.O., Geffen, A.J., MacKenzie, K. ,Nash, R.D.M., Jansen, S., Kay, S., Kelly, C.J, O'Leary, D. B., Schlickeisen, J., Schon, P.-J., Watts, P. C; and Zimmermann, C. 2007. The scientific implications of the EU Project WESTHER (Q5RS - 2002 – 01056) to the assessment and management of the herring stocks to the west of the British Isles. ICESCM 2007/L:11.

ICES. 1994. Report of the Study Group on Herring Assessment and Biology in the Irish Sea and Adjacent Waters. ICES CM 1994/H :5. 67pp.

IWDG (2004b) Cetacean Distribution and Relative Abundance Survey during North-west Herring Acoustic Survey 2004. http://www.iwdg.ie/downloads/CEHerringAcousticSurvey2004.PDF

Molloy, J., E. Barnwall, and J. Morrison. 1993. Herring Tagging Experiments around Ireland, 1991. Fishery Leaflet, 154: 7pp.

Molloy, J. (1968). "Herring investigations on the southwest coast of Ireland 1967." ICES CM 1968/H:14: 10 pp

O'Donnell, C., Griffin, K., Lynch D., Ullgren J., Goddijn L., Wall D. & Mackey M. (2004). Celtic Sea Herring Acoustic Survey Cruise Report, 2004.

O'Donnell, C. Doonan I. & Lynch D. (2005a) Celtic Sea Herring Acoustic Survey Cruise Report, FV Regina Ponti 2005.

O'Donnell, C. Doonan I., Lynch D., Dransfeld, L. & Wall D. (2005b) Celtic Sea Herring Acoustic Survey Cruise Report, RV Celtic explorer 2005.

O'Donnell, C., Doonan, I., Lynch, D., Egan, A., Boyd, J., Wall, D. and Ulgren, J (2006) Celtic Sea Herring Acoustic Survey Cruise Report, 2006.

O'Donnell, C., Egan, A., Lynch, D., Dransfeld, L., Boyd, J., Lyons, K. and Wall, D (2007) Celtic Sea Herring Acoustic Survey Cruise Report, 2007.

O'Donnell, C., Mullins E., Johnston, G., Lyons, K., Bethke, E., Holst, G. and Wall, D. (2008) Blue whiting Acoustic Survey Cruise Report, 2008

O'Donnell, C., Saunders, R.A., Lynch, D., Lyons, K. and Wall, D (2008) Celtic Sea Herring Acoustic Survey Cruise Report, 2008.

Wall D., O'Brien J., Meade J. & Allen B.M. (2006) Summer distribution and relative abundance of cetaceans off the west coast of Ireland. Biology and Environment: Proceedings of the Royal Irish Academy, 106B (2), 135 - 142.

5 Tables and Figures

Table 1. Survey Strata details. Celtic Sea herring acoustic survey, October 2009.

Strata no.	Strata name	Survey type	Transect type	Total transects	Active transects	Transect spacing	Total transect distance (nmi)	Strata area (nmi2)
1 (a,b)	SW Shannon	Broad scale	Parallel	26	14	4	192	727
2	Inside Shannon	Broad scale	Zigzag	7	7	\	41	39
3	Dingle	Broad scale	Zigzag	9	9	\	69	99
4 (a,b)	SW corner	Broad scale	Parallel	15	8	4	179	548
5	Kenmare	Broad scale	Zigzag	7	7	\	43	61
6	Bantry	Broad scale	Zigzag	8	7	\	35	34
7	Dunmanus	Broad scale	Zigzag	7	7	\	26	9
8	Mizen area	Broad scale	Parallel	27	14	4	310	770
9	Offshore CS	Broad scale	Parallel	63	32	2	1002	1932
10 (a,b,c,d,e)	Inshore CS	Broad scale	Parallel	61	34	2	631	1106
11	Baginbun	Spawning grid	Parallel	17	9	1	67	29
12	Tramore	Spawning grid	Parallel	31	16	1	110	85
13	Waterford Hbr	Broad scale	Zigzag	4	4	\	11	4
14	Ballycotton	Spawning grid	Parallel	32	16	1	115	104
15	Daunt	Spawning grid	Parallel	25	13	1	80	69
16	Stags	Spawning grid	Parallel	9	5	1	97	16
17	Dingle_S	Spawning grid	Parallel	11	6	1	24	9
18	Dingle_N	Spawning grid	Parallel	11	6	1	22	7
19	Kerry Head	Spawning grid	Parallel	23	12	1	136	61
			Total	393	226		3190	5705.98

Table 2. Settings for the Simrad ER60 echosounder, employed during the Celtic Sea herring acoustic survey, October 2009.

Echo sounder:		Simrad ER 60
Frequency:		38 kHz
Transducer:		ES 38B- Serial
Absorption Coefficient:		0.067 dB/Km (manual)
Pulse length:		1.024 m/s
Bandwidth:		2.43 KHz
Transmitting Power:		2000 W (Max)
Angle Sensitivity:		13.9 dB
2- way beam angle:		-20.60°
Gain:		25.71
SA Correction:		-0.63
3 dB Beam W	Alongship:	6.97°
	Athwartship:	7.00°
Max Range:		500m

Note: Calibration report available (38KHz) in Appendix

Table 3. Catch table from directed net hauls during the Celtic Sea herring acoustic survey, October 2009.

No.	Date	Lat. N	Lon. W	Time	Bottom (m)	Target (m)	Bulk Catch (Kg)	Herring %	Mackerel %	Scad %	Sprat %	Pilchard %	Others%*
1	09-Oct	52,36.415	10,15.50	11:06	95	85	17.71	0.0	1.3	12.7	83.2	0.0	2.8
2	10-Oct	51,58.743	10,29.493	6:21	73	10	21.94	0.0	27.8	0.7	68.4	0.0	3.1
3	10-Oct	52,05.455	10,18.249	10:23	35	25	200	0.3	40.2	0.0	59.5	0.0	0.0
4	11-Oct	51,34.11	10,28.209	9:47	102	22	156.42	0.0	28.9	23.3	0.0	0.0	47.8
5	11-Oct	51,30.227	10,24.073	13:52	105	55	31.87	0.0	98.0	1.0	0.0	0.0	1.0
6	12-Oct	51,19.889	10,00.623	2:25	103	17	182.82	0.0	0.0	100.0	0.0	0.0	0.0
7	12-Oct	51,18.873	9,28.687	14:56	80	75	145.44	91.7	3.2	0.1	0.6	0.0	4.4
8	13-Oct	51,19.72	8,26.805	10:35	90	60	0	0.0	0.0	0.0	0.0	0.0	0.0
9	13-Oct	51,5.951	8,26.69	13:53	n/a	n/a	1200	99.3	0.5	0.0	0.1	0.0	0.2
10	14-Oct	51,24.094	8,4.645	12:14	84	79	127.43	32.7	14.3	14.6	29.4	0.0	9.0
11	14-Oct	51,11.720	7,58.576	18:30	100	50	26.58	2.9	5.3	4.5	82.4	0.0	4.9
12	14-Oct	51,17.967	7,58.441	21:33	90	84	86.132	99.8	0	0.00	0.00	0.00	0.2
13	15-Oct	51,26.099	7,55.086	1:05	82	12	2000	65.8	34.2	0.0	0.0	0.0	0.1
14	15-Oct	51'2.201	7'45.505	12:33	96	91	36.626	30.1	0.0	0.0	65.9	0.0	4.0
15	15-Oct	51'16.936	7'39.098	22:50	87	17	56.147	88.1	1.2	0.0	0.8	0.0	10.0
16	16-Oct	51'20.822	7'29.697	11:57	82	76	250	15.2	15.3	0.0	68.6	0.0	0.9
17	16-Oct	51'8.464	7'29.661	14:19	91	86	2500	92.6	5.2	2.1	0.0	0.0	0.2
18	17-Oct	51'05.041	7'223.244	0:42	90	82	2000	99.6	0.0	0.0	0.0	0.0	0.4
19	17-Oct	51'32.597	7'16.359	7:55	76	66	31.634	0.0	99.6	0.0	0.0	0.0	0.3
20	17-Oct	51'22.161	7'9.893	16:06	82	74	250	39.4	16.5	0.1	34.1	0.0	9.8
21	18-Oct	51'23.849	6'50.374	10:54	83	61	240	1.8	2.7	0.0	94.7	0.0	0.9
22	19-Oct	52'2.0384	7'8.189	18:31	50	25	2500	96.5	3.2	0.0	0.0	0.3	0.0
23	20-Oct	52'3.758	7'14.873	11:50	37	26	2000	95.6	1.8	0.0	0.0	2.6	0.0
24	20-Oct	52'6.820	7'18.023	14:12	23	3	5000	99.7	0.1	0.1	0.0	0.1	0.1
25	20-Oct	51'52.947	7'15.974	18:31	67	52	121.065	1.5	11.8	0.0	55.2	0.0	31.5
26	21-Oct	51'48.758	7'28.258	10:20	67	52	292.14	22.6	33.0	5.4	38.4	0.0	0.7
27	21-Oct	51'49.625	7'34.283	18:43	65	33	104.68	1.3	17.8	0.0	66.9	0.0	14.0
28	22-Oct	51'36.368	7'48.675	5:42	85	35	5000	96.7	3.3	0.0	0.0	0.0	0.0
29	22-Oct	51'50.170	7'43.250	14:09	46	30	37.125	16.99	14.55	0.04	68.15	0.04	0.2
30	23-Oct	51'29.327	8'11.388	9;26	84	42	107.819	0.04	13.62	64.81	21.33	0	0.2

Table 4. Length-frequency (%) of herring hauls used for calculating 'definitely' and 'probably' abundance categories. Celtic Sea herring acoustic survey, October 2009.

Length (cm)	7	9	12	13	15	17	18	22	23	24	28
15							13				
15.5			1				23				
16							26				
16.5							23				
17							9				
17.5							4				
18							2				
18.5											
19		1		7							2
19.5		2		6						2	2
20		4		15						2	4
20.5		6		15	1	3			1	2	11
21		7		19	1	5			1	6	7
21.5		17		16	2	2		2	1	5	12
22	1	13		11	2	5		1	2	9	22
22.5	2	8		7	3	6		1	5	7	10
23	2	5		3	3	3		2	2	3	8
23.5	2	5	1		3	4		2	2	2	2
24	4	4			6	3		3	2	1	1
24.5	7	6	3	1	4	9		5	4	3	3
25	11	6	5		11	12		9	12	6	4
25.5	14	6	11		16	18		18	12	9	3
26	14	3	22		22	16		22	15	13	3
26.5	16	5	26		13	8		22	19	15	3
27	14	2	18		9	2		3	10	8	2
27.5	8		8		2	2		6	9	5	
28	4		4		2	1		3	1	1	1
28.5			1					1	1		
29	1					1			1	1	
Total	100	100	100	100	100	100	100	100	100	100	100

Table 5. Herring Age length key from combined trawl samples. Celtic Sea herring acoustic survey, October 2009.

Length class (cm)	0	1	2	3	4	5	6	7	8	9	Total
12.5	5										5
13	13										13
13.5	15										15
14	30										30
14.5	50										50
15	97										97
15.5	72										72
16	64										64
16.5	18										18
17	9										9
17.5	3										3
18	1	1									2
18.5	1	4									5
19	1	5									6
19.5		11									11
20		10									10
20.5		24									24
21		30									30
21.5		19	1								20
22		28	3								31
22.5		22	3								25
23		14	10								24
23.5		2	5								7
24			13	3							16
24.5			12	5							17
25			14	34	2	1					51
25.5			9	49	4	5					67
26			4	52	20	23	1		1		101
26.5				38	15	36	1				90
27				9	7	29	5	1			51
27.5				2	5	17	2	2	1		29
28				1	2	6	2		3	1	15
28.5				1	1	1			1		4
Total	379	170	74	194	56	118	11	3	6	1	1012
%	37.45	16.80	7.31	19.17	5.53	11.66	1.09	0.30	0.59	0.10	

Table 6. Total biomass (000's tonnes) of herring at age (winter rings), by strata as derived from acoustic estimate of abundance**.** Celtic Sea herring acoustic survey, October 2009.

Strata	0	1	2	3	4	5	6	7	8	9	Total
1	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0
8	0.1	0.6	2.7	7.7	2.4	5.8	0.7	0.2	0.4	0.1	20.6
9	5.9	14.7	3.4	6.2	1.6	3.2	0.3	0.1	0.2	0	35.4
10	0.5	10.7	3.2	4.9	1.4	2.9	0.3	0.1	0.2	0	24
11	0	0	0	0	0	0	0	0	0	0	0
12	0	4.4	3.8	12.5	4	9	0.8	0.3	0.5	0.1	35.5
13	0	0	0	0	0	0	0	0	0	0	0
14	0	0.5	0.3	0.8	0.2	0.5	0	0	0	0	2.4
15	0	0.4	0.1	0.1	0	0	0	0	0	0	0.6
16	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0.1	0.2	0.1	0.1	0	0	0	0	0.5
19	0	0	0	0	0	0	0	0	0	0	0
Total	6.5	31.2	13.6	32.2	9.7	21.7	2.1	0.7	1.3	0.2	119.1
%	5.4	26.2	11.4	27	8.1	18.2	1.8	0.6	1.1	0.1	100

Table 7. Herring abundance (millions) at age (winter rings), by strata as derived from acoustic estimate of abundance. Celtic Sea herring acoustic survey, October 2009.

Strata	0	1	2	3	4	5	6	7	8	9	Total
1	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0
8	3.15	5.77	21.15	49.94	14.20	33.30	3.60	1.11	1.80	0.33	134.36
9	220.04	188.14	29.02	40.62	9.59	18.62	1.59	0.37	0.88	0.14	509.00
10	14.69	126.81	27.71	31.96	8.10	16.98	1.55	0.43	0.88	0.13	229.23
11	0	0	0	0	0	0	0	0	0	0	0
12	0	50.53	30.49	80.55	23.78	51.73	4.60	1.62	2.59	0.26	246.13
13	0	0	0	0	0	0	0	0	0	0	0
14	1.48	5.61	2.40	5.06	1.39	2.99	0.27	0.09	0.15	0.01	19.46
15	0.02	4.39	0.78	0.53	0.11	0.21	0.02	0.00	0.01	0.00	6.06
16	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0
18	0.08	0.14	0.50	1.18	0.34	0.79	0.09	0.03	0.04	0.01	3.18
19	0	0	0	0	0	0	0	0	0	0	0
Total	239.45	381.39	112.04	209.85	57.49	124.63	11.71	3.65	6.35	0.88	1147.42
%	20.87	33.24	9.76	18.29	5.01	10.86	1.02	0.32	0.55	0.08	100.00
Cv (%)	47.20	41.50	25.40	24.60	25.40	26.30	28.00	28.80	26.40	29.50	23.10

Table 8. Herring biomass (000's tonnes) at maturity by strata. Totals do not account for the "possibly" herring classification. Celtic Sea herring acoustic survey, October 2009.

Strata	Immature	Mature	Spent	Total
1	0	0	0	0
2	0	0	0	0
3	0	0	0	0
4	0	0	0	0
5	0	0	0	0
6	0	0	0	0
7	0	0	0	0
8	0.3	20.3	0	20.6
9	16.6	18.9	0	35.4
10	7.7	16.3	0	24
11	0	0	0	0
12	2.9	32.6	0	35.5
13	0	0	0	0
14	0.4	2.1	0	2.4
15	0.3	0.3	0	0.6
16	0	0	0	0
17	0	0	0	0
18	0	0.5	0	0.5
19	0	0	0	0
Total	28.1	90.9	0	119.1
%	23.6	76.4	0	100

Table 9. Herring abundance (millions) at maturity by strata. Totals do not account for the possibly herring classification. Celtic Sea herring acoustic survey, October 2009.

Strata	Immature	Mature	Spent	Total
1	0	0	0	0
2	0	0	0	0
3	0	0	0	0
4	0	0	0	0
5	0	0	0	0
6	0	0	0	0
7	0	0	0	0
8	5.75	128.61	0	134.36
9	360.40	148.61	0	509.00
10	102.68	126.55	0	229.23
11	0	0	0	0
12	34.06	212.07	0	246.13
13	0	0	0	0
14	5.31	14.15	0	19.46
15	3.07	2.99	0	6.06
16	0	0	0	0
17	0	0	0	0
18	0.14	3.05	0	3.18
19	0	0	0	0
Total	511.40	636.02	0	1147.42
%	44.57	55.43	0	100.00

Table 10. Herring length at age (winter rings) as abundance (millions) and biomass (000's tonnes). Celtic Sea herring acoustic survey, October 2009.

Length (cm)	0	1	2	3	4	5	6	7	8	9	Abund. (mill)	Bio. (000 t)	Mn wt (g)
8.5	0.53										0.53		3.90
9	0.53										0.53		4.70
9.5	0.53										0.53		5.60
10	1.06										1.06	0.01	6.70
10.5	1.06										1.06	0.01	7.80
11	2.64										2.64	0.02	9.10
11.5	5.29										5.29	0.06	10.60
12	10.28										10.28	0.13	12.20
12.5	4.15										4.15	0.06	13.90
13	7.95										7.95	0.13	15.80
13.5	5.84										5.84	0.10	17.90
14	10.81										10.81	0.22	20.20
14.5	21.99										21.99	0.50	22.70
15	29.72										29.72	0.75	25.40
15.5	44.33										44.33	1.25	28.30
16	39.87										39.87	1.25	31.40
16.5	31.02										31.02	1.08	34.80
17	12.83										12.83	0.49	38.40
17.5	5.66										5.66	0.24	42.30
18	0.93	1.87									2.80	0.13	46.50
18.5	0.13	0.54									0.67	0.03	50.90
19	2.31	11.50									13.80	0.77	55.60
19.5		17.34									17.34	1.05	60.60
20		35.94									35.94	2.37	65.90
20.5		51.59									51.59	3.69	71.50
21		55.76									55.76	4.32	77.50
21.5		61.86	3.26								65.12	5.46	83.80
22		72.23	7.76								79.99	7.24	90.50
22.5		48.43	6.60								55.03	5.36	97.50
23		19.52	13.96								33.47	3.51	104.90
23.5		4.81	12.00								16.81	1.89	112.60
24			13.39	3.10							16.49	1.99	120.80
24.5			24.07	10.03							34.10	4.41	129.40
25			17.47	42.37	2.48	1.27					63.59	8.80	138.40
25.5			9.93	54.16	4.45	5.56					74.09	10.95	147.80
26			3.60	46.29	17.80	20.49	0.90		0.90		89.97	14.19	157.70
26.5				38.97	15.42	36.94	1.02				92.34	15.52	168.00
27				9.94	7.74	32.14	5.54	1.13			56.49	10.10	178.80
27.5				2.52	6.28	21.41	2.52	2.52	1.24		36.50	6.94	190.10
28				0.87	1.74	5.22	1.74		2.61	0.87	13.06	2.64	201.90
28.5				0.79	0.79	0.79			0.79		3.16	0.68	214.10
29				0.80	0.80	0.80			0.80		3.21	0.73	226.90
TSN (mill)	0.38	121.88	99.21	209.85	57.49	124.63	11.71	3.65	6.35	0.87	636.02		
TSB (000 t)	0.02	10.73	12.42	32.18	9.68	21.66	2.13	0.68	1.26	0.18		90.94	
Mn wt (g)	27.10	81.80	121.60	153.30	168.30	173.80	182.10	186.60	198.00	201.90			
Mn length (cm)	15.40	21.50	24.20	26.00	26.70	27.00	27.40	27.60	28.10	28.20			

Table 11. Herring biomass and abundance by survey strata. Celtic Sea herring acoustic survey, October 2009.

Stratum	No. transects	No. schools	Def schools	Mixed schools	Prob. Schools	Zero transects (%)	Def. biomass	Mixed biomass	Prob. biomass	Biomass (000 t)	SSB (000 t)	Abundance (millions)
1	14	0	0	0	0	100	0	0	0	0	0	0
2	6	0	0	0	0	100	0	0	0	0	0	0
3	9	0	0	0	0	100	0	0	0	0	0	0
4	8	0	0	0	0	100	0	0	0	0	0	0
5	7	0	0	0	0	100	0	0	0	0	0	0
6	7	0	0	0	0	100	0	0	0	0	0	0
7	5	0	0	0	0	100	0	0	0	0	0	0
8	14	39	35	0	4	86	19.8	0	0.8	20.6	20.3	134.4
9	32	325	97	194	34	38	20	13.3	2.2	35.4	18.9	509.0
10	35	94	34	52	8	83	16.1	0.4	7.5	24.0	16.3	229.2
11	9	0	0	0	0	100	0	0	0	0.0	0.0	0.0
12	17	117	116	0	1	53	35.4	0	0	35.5	32.6	246.1
13	4	0	0	0	0	100	0	0	0	0.0	0.0	0.0
14	17	63	1	58	4	65	0.5	0.2	1.7	2.4	2.1	19.5
15	11	3	0	0	3	91	0	0	0.6	0.6	0.3	6.1
16	5	0	0	0	0	100	0	0	0	0.0	0.0	0.0
17	6	0	0	0	0	100	0	0	0	0.0	0.0	0.0
18	6	3	0	0	3	83	0	0	0.5	0.5	0.5	3.2
19	12	0	0	0	0	100	0	0	0	0.0	0.0	0.0
Total	224	644	283	304	57	80	91.8	14	13.3	119.1	90.9	1147.4
Cv (%)	-	-	-	-	-	-	-	-	-	22.7	24.0	23.1

Table 12. Celtic Sea and VIIj Herring acoustic survey time series. Abundance (millions), TSB and SSB (000's tonnes). Age in winter rings.

Season Age (Rings)	**1995 1996**	**1996 1997**	**1997 1998**	**1998 1999**	**1999 2000**	**2000 2001**	**2001 2002**	**2002 2003**	**2003 2004**	**2004 2005**	**2005 2006**	**2006 2007**	**2007 2008**	**2008 2009**	**2009 2010**
0	202	3	-	0	-	25	40	0	24	-	2	-	1	2	0
1	25	164	-	30	-	102	28	42	13	-	65	21	106	63	122
2	157	795	-	186	-	112	187	185	62	-	137	211	70	295	99
3	38	262	-	133	-	13	213	151	60	-	28	48	220	111	210
4	34	53	-	165	-	2	42	30	17	-	54	14	31	162	57
5	5	43	-	87	-	1	47	7	5	-	22	11	9	27	125
6	3	1	-	25	-	0	33	7	1	-	5	1	13	6	12
7	1	15	-	24	-	0	24	3	0	-	1	-	4	5	4
8	2	0	-	4	-	0	15	0	0	-	0	-	1	-	6
9	2	2	-	2	-	0	52	0	0	-	0	-	0	-	1
Abundance	469	1338	-	656	-	256	681	423	183	-	312	305	454	671	636
SSB	36	151	-	100	-	20	95	41	20	-	33	36	46	93	91
CV	53	26	-	36	-	100	88	49	34	-	48	35	25	20	24

Table 13. Sprat biomass and abundance by survey strata. Celtic Sea herring acoustic survey, October 2009.

Stratum	No. tran-sects	No. schools	Def schools	Mixed schools	Prob. Schools	Zero transects (%)	Def. biomass	Mixed biomass	Prob. Biomass	Biomass (000 t)	Abundance (mill)
1	14	37	26	11	0	79	0.7	2.5	0	3.2	248.543
2	6	0	0	0	0	100	0	0	0	0	0
3	9	80	0	80	0	11	0	6.4	0	6.4	571.7
4	8	3	0	3	0	88	0	0.3	0	0.3	47.609
5	7	0	0	0	0	100	0	0	0	0	0.0
6	7	0	0	0	0	100	0	0	0	0	0
7	5	0	0	0	0	100	0	0	0	0	0
8	14	0	0	0	0	100	0	0	0	0	0.0
9	32	76	76	0	0	91	3.8	0	0	3.8	364.7
10	35	43	0	43	0	91	0	2.5	0	2.5	185.237
11	9	0	0	0	0	100	0	0	0	0	0
12	17	0	0	0	0	100	0	0	0	0	0
13	4	0	0	0	0	100	0	0	0	0	0
14	17	0	0	0	0	100	0	0	0	0	0
15	11	0	0	0	0	100	0	0	0	0	0
16	5	0	0	0	0	100	0	0	0	0	0
17	6	0	0	0	0	100	0	0	0	0	0
18	6	0	0	0	0	100	0	0	0	0	0
19	12	0	0	0	0	100	0	0	0	0	0
Total	224	239	102	137	0	92	4.5	11.7	0	16.2	1417.9
Cv (%)	-	-	-	-	-	-	-	-	-	30.6	28.8

Table 14. Sightings, counts and group size ranges for cetaceans sighted during current survey. Celtic Sea herring acoustic survey, October 2009.

Species	No. Sightings	No. Individuals	Range of Group Size	Juveniles/ Calves
Common dolphin	40	814	2-150	8
Risso's dolphin	2	5	1-4	-
Fin whale	4	7	1-2	
Minke whale	13	14	1-2	-
Unidentified dolphin	10	157	1-50	-
Unidentified whale (blow)	5	14	1-10	-

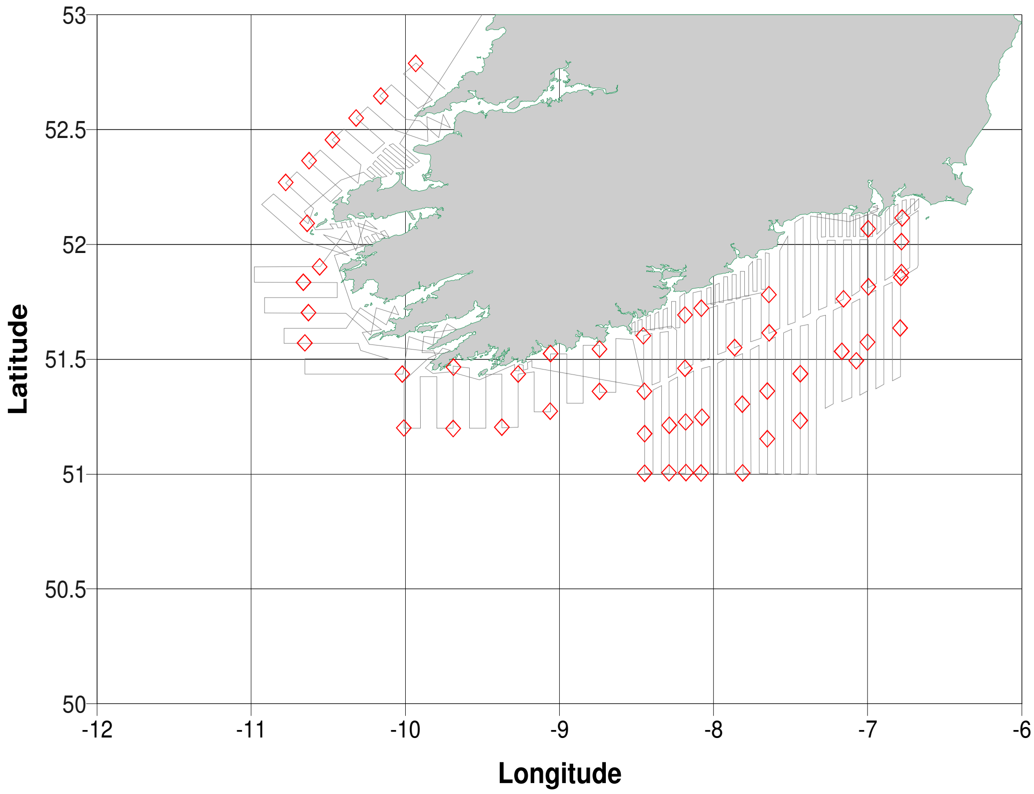

Figure 1. Cruise track (grey line) and CTD positions during the Celtic Sea herring acoustic survey, October 2009.

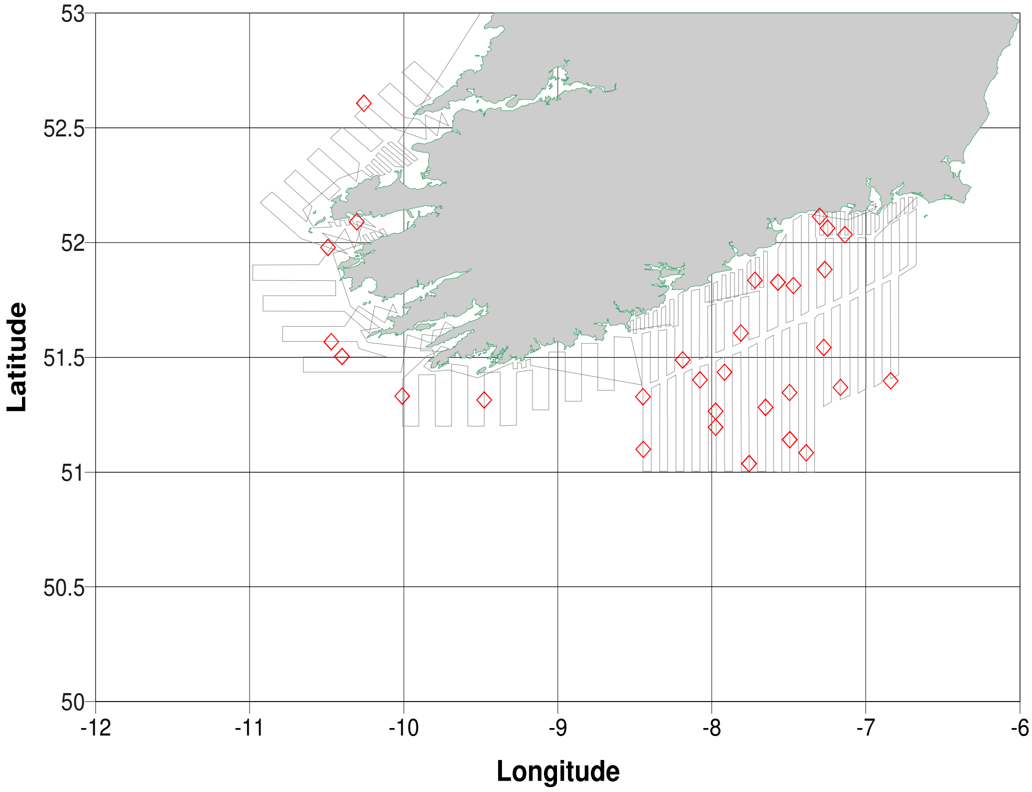

Figure 2. Haul positions. Celtic Sea herring acoustic survey, October 2009.

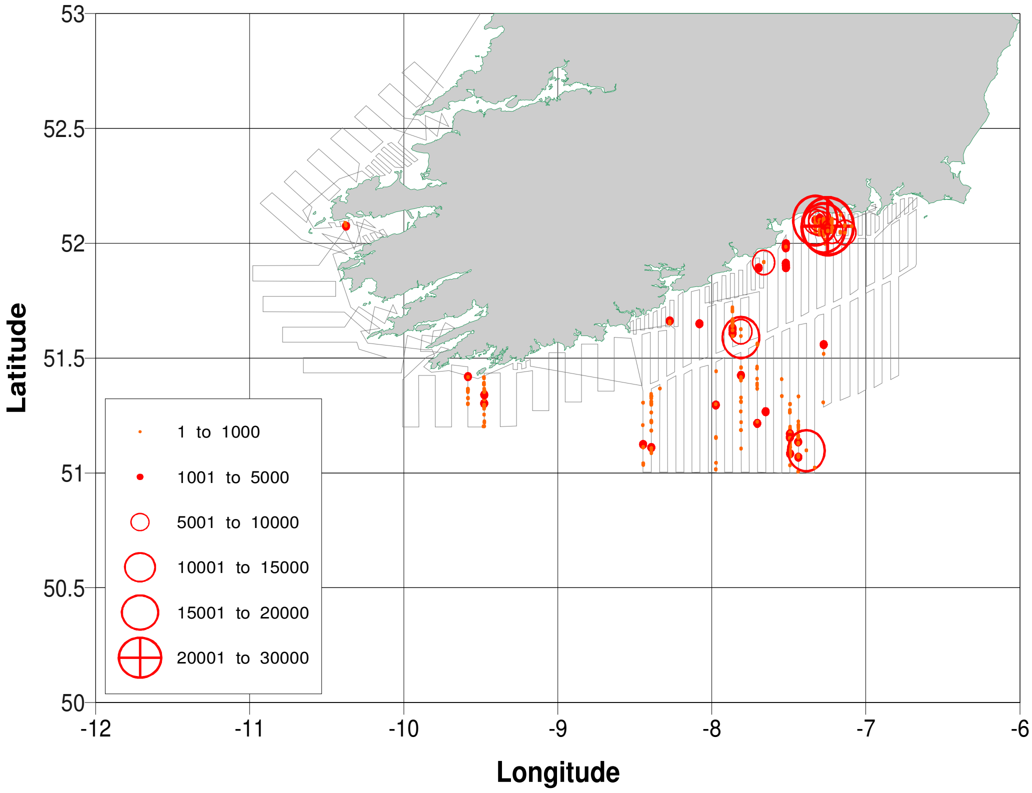

Figure 3. Weighted herring NASC (Nautical area scattering coefficient) plot showing the distribution of “definitely” and “probably” categories. Celtic Sea herring acoustic survey, October 2009.

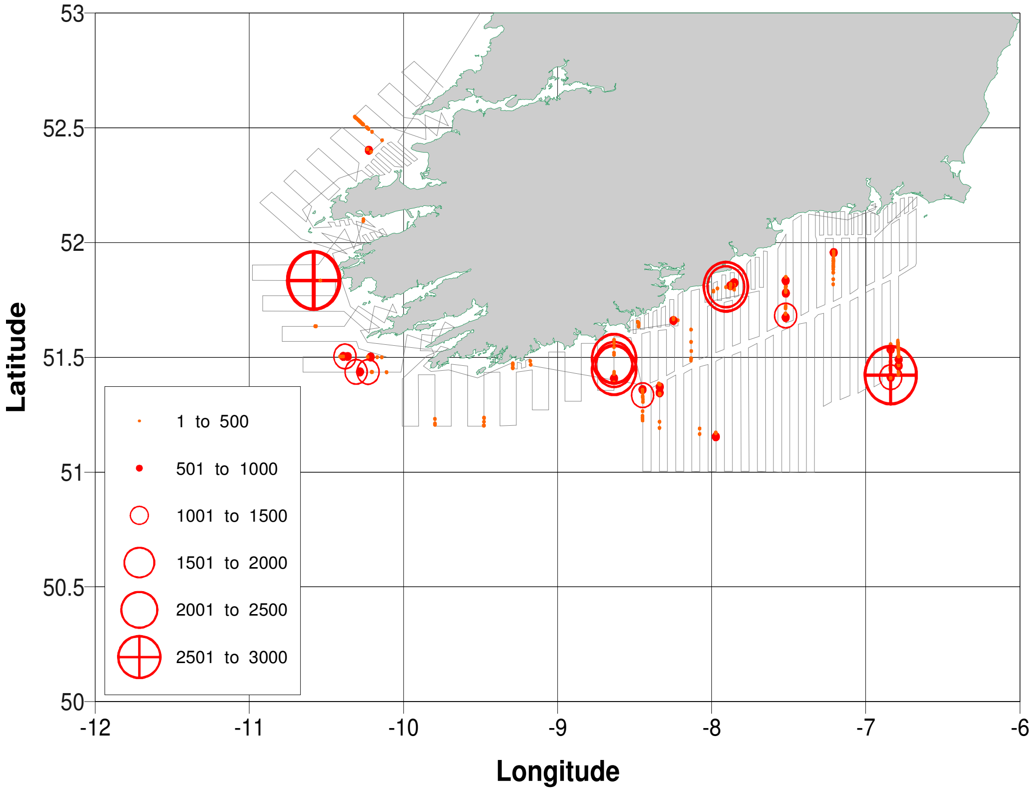

Figure 4. Weighted Sprat NASC (Nautical area scattering coefficient) plot showing the distribution of “definitely” and “probably” categories. Celtic Sea herring acoustic survey, October 2009.

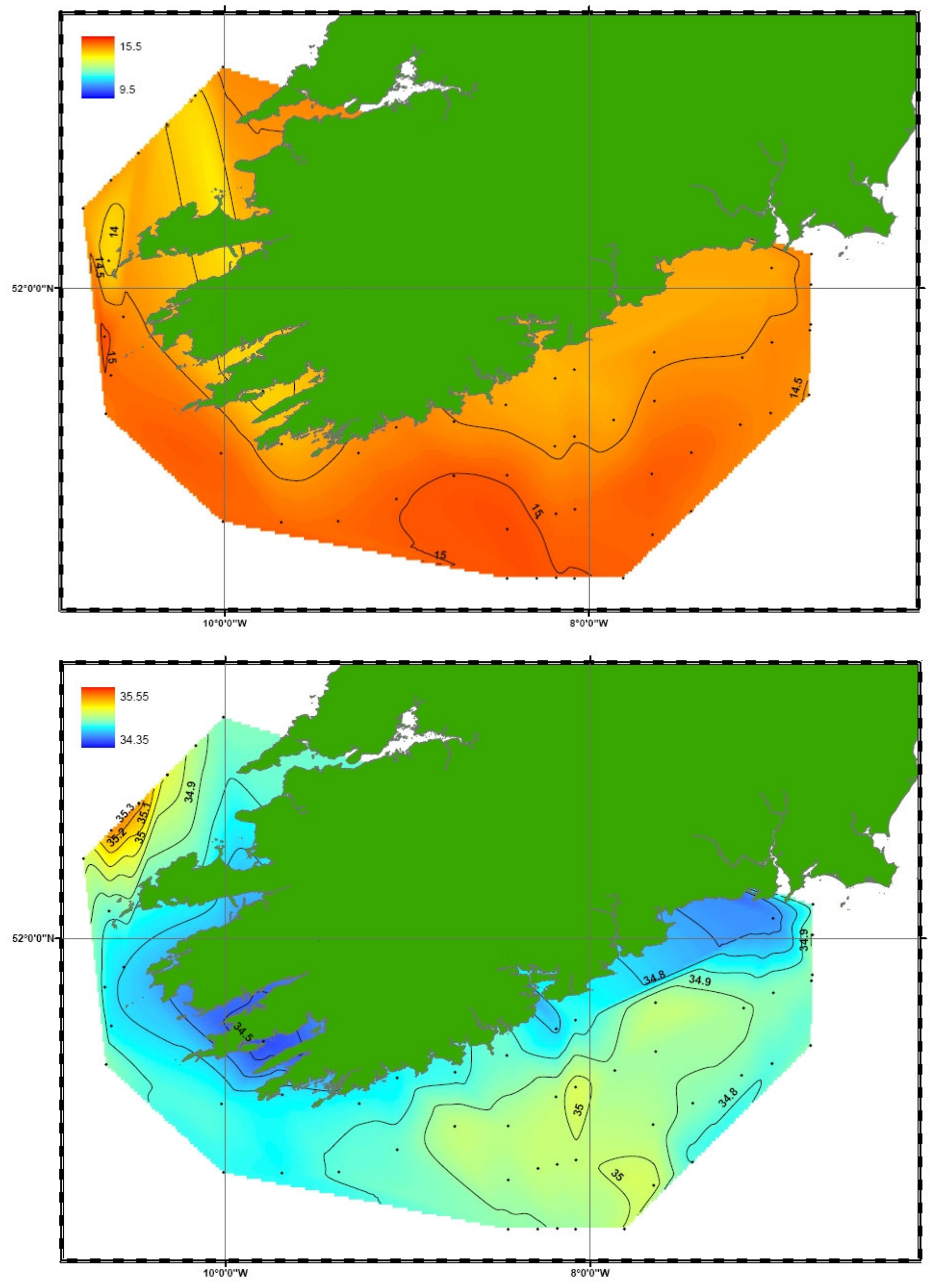

Figure 5. Surface plots of temperature (above) and salinity (below) at 5 m from combined CTD cast data. Celtic Sea herring acoustic survey, October 2009.

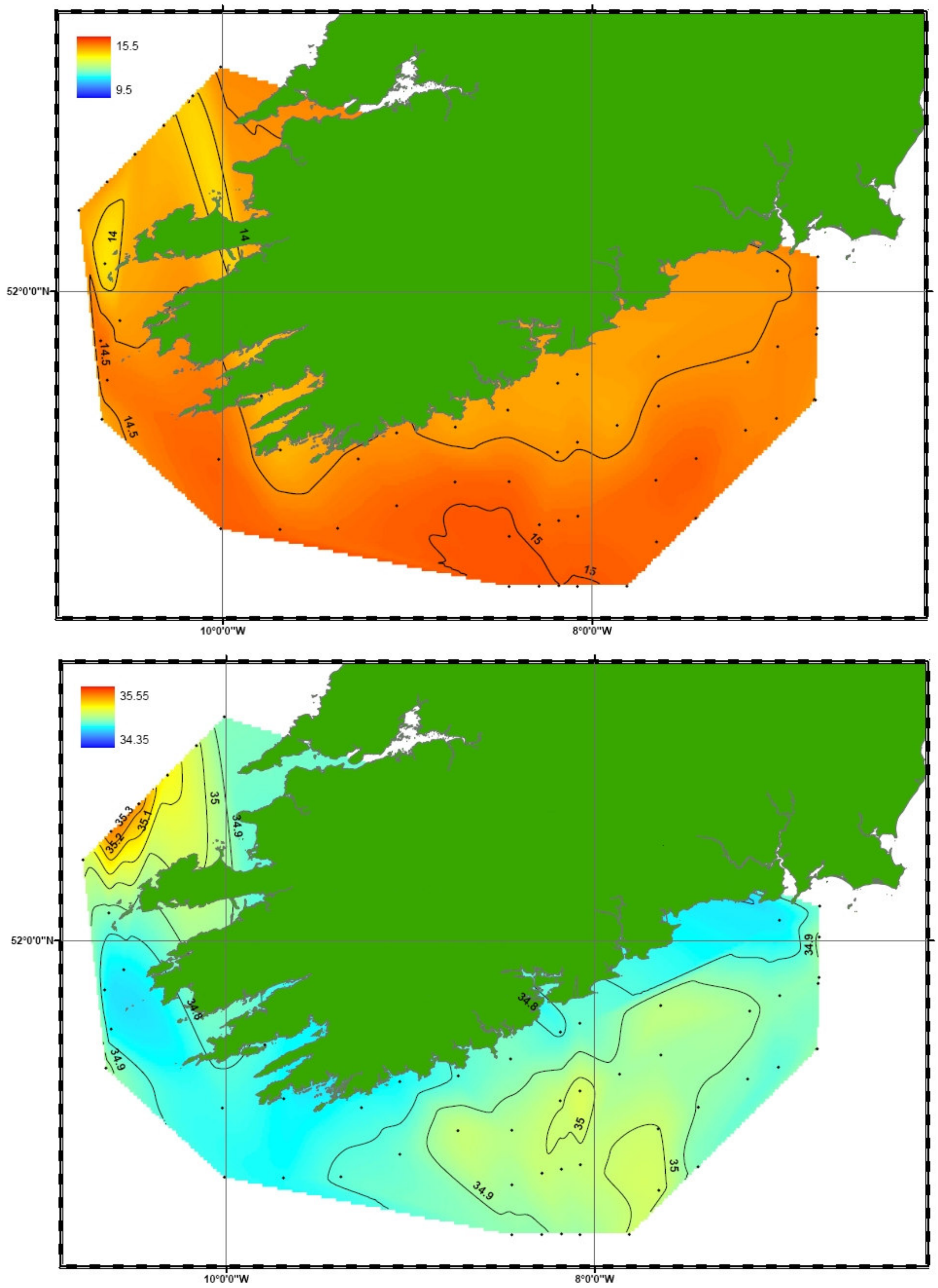

Figure 6. Surface plots of temperature (above) and salinity (below) at 20 m from combined CTD cast data. Celtic Sea herring acoustic survey, October 2009.

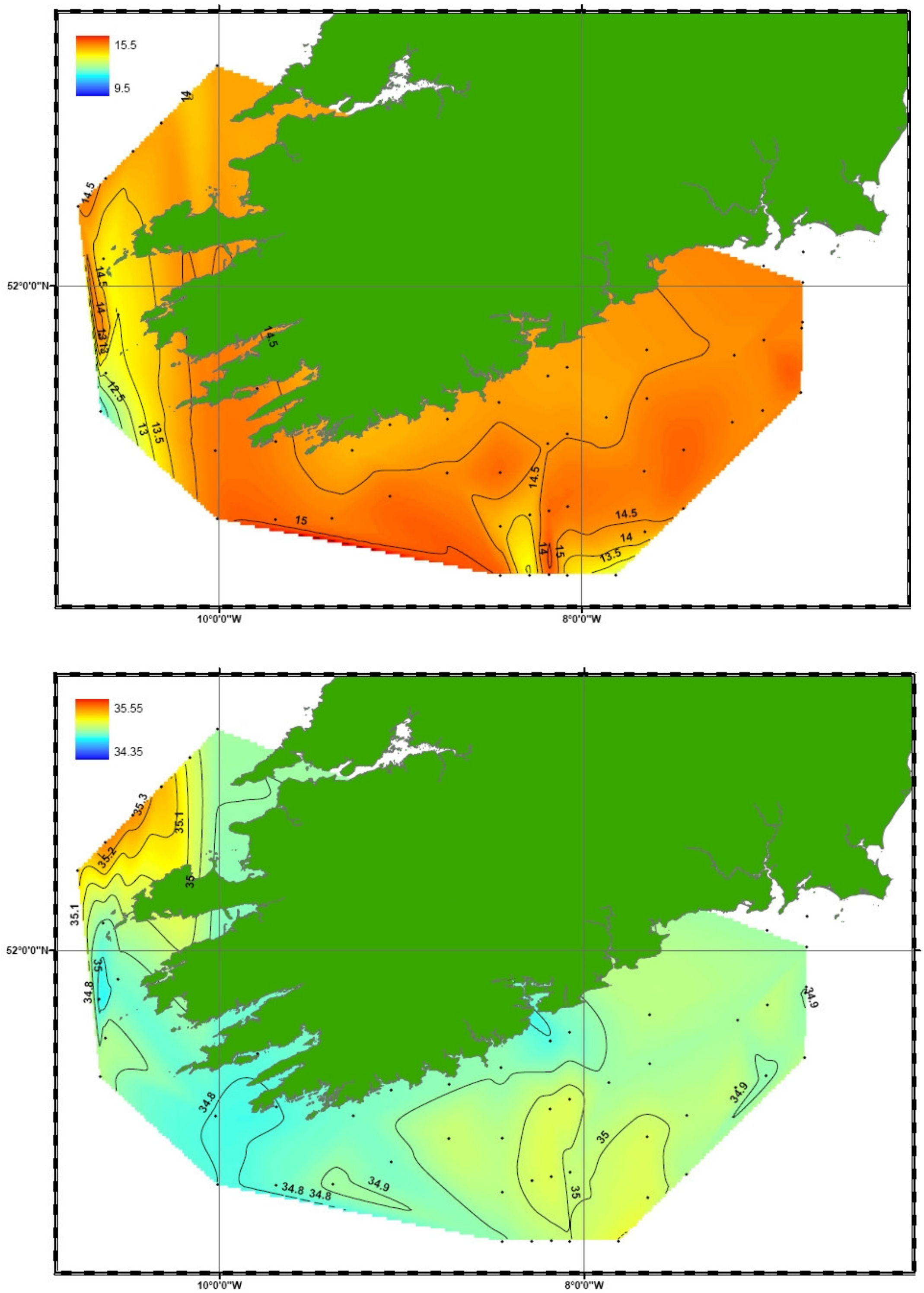

Figure 7. Surface plots of temperature (above) and salinity (below) at 40m from combined CTD cast data. Celtic Sea herring acoustic survey, October 2009.

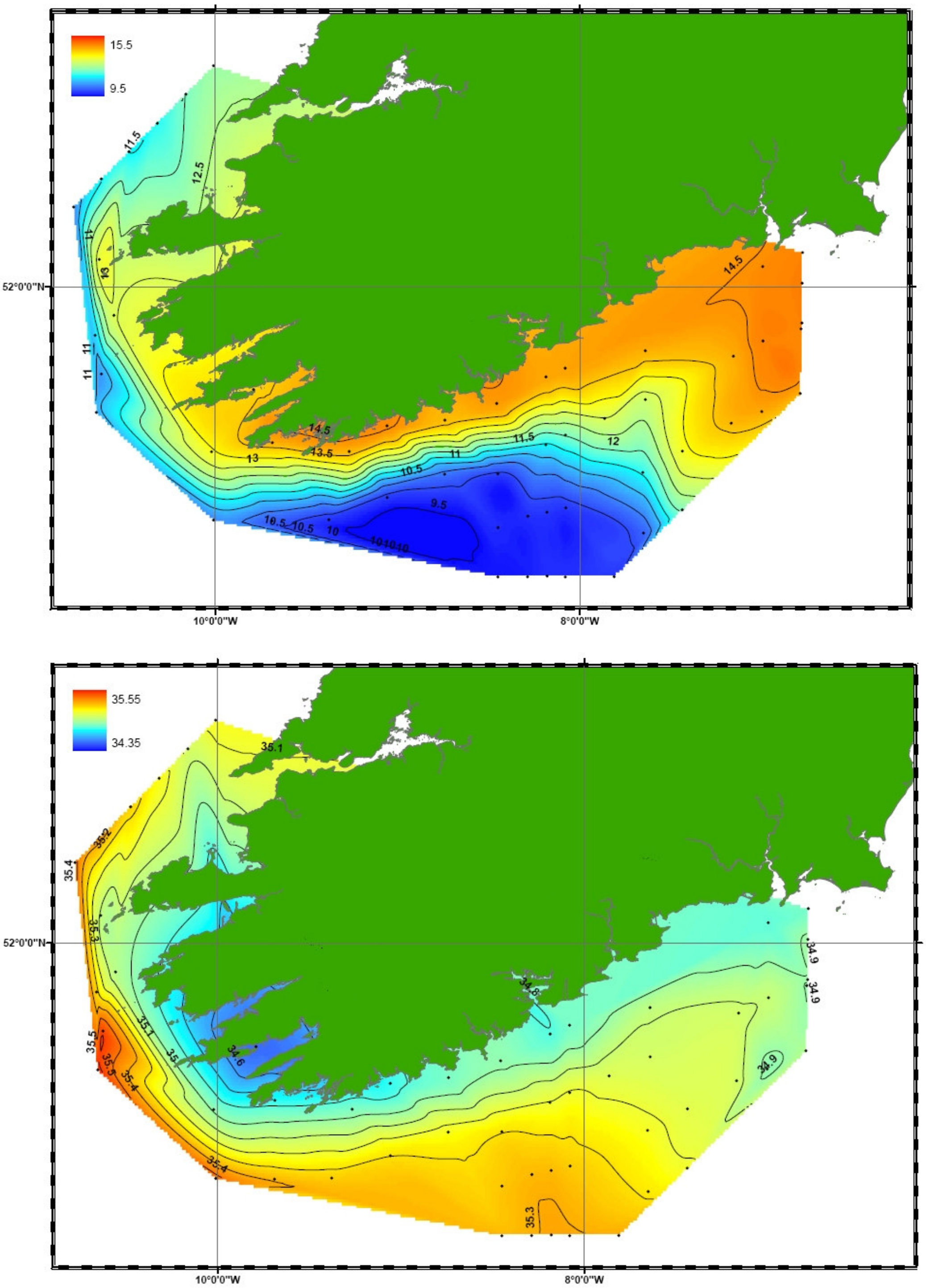

Figure 8. Surface plots of temperature (above) and salinity (below) at >60 m from combined CTD cast data. Celtic Sea herring acoustic survey, October 2009.

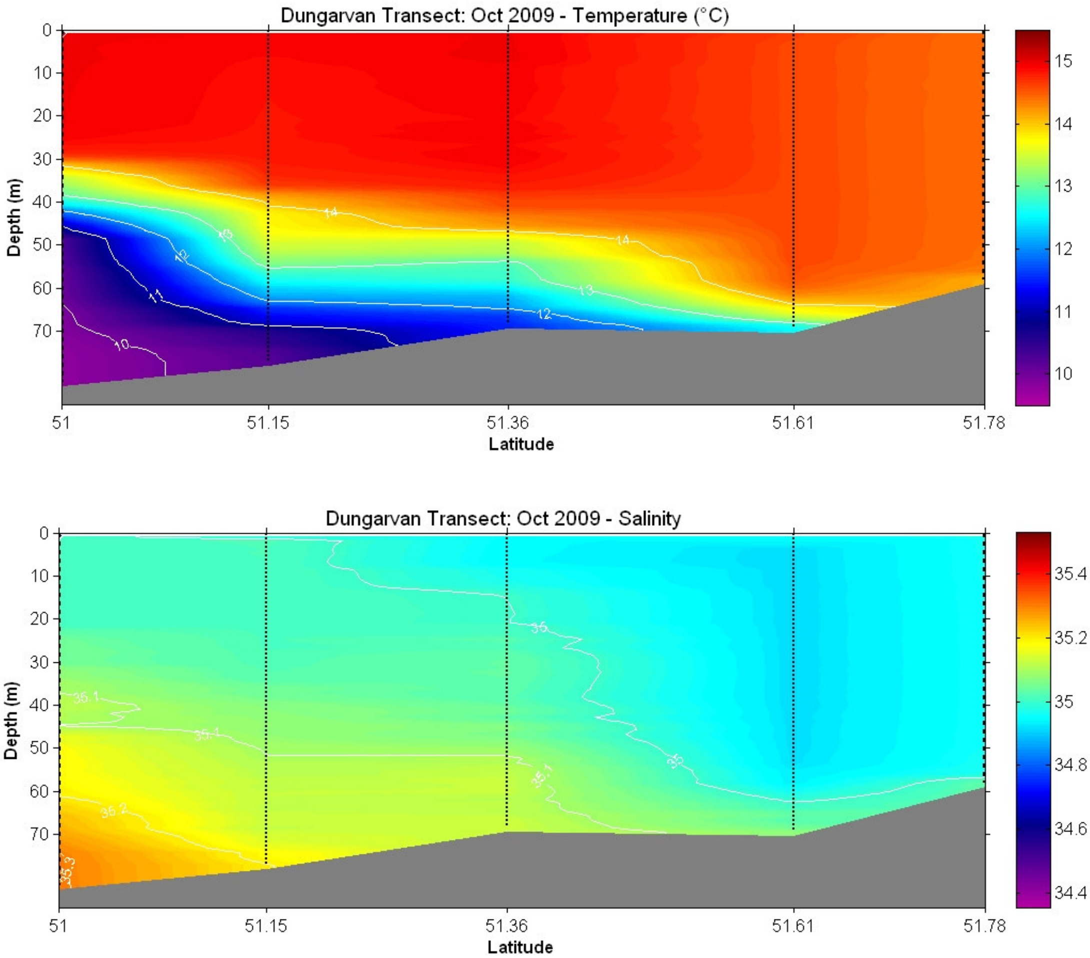

Figure 9. Vertical distribution of temperature (above) and salinity (below) along the Dungarvan transect. Celtic Sea herring acoustic survey, October 2009.

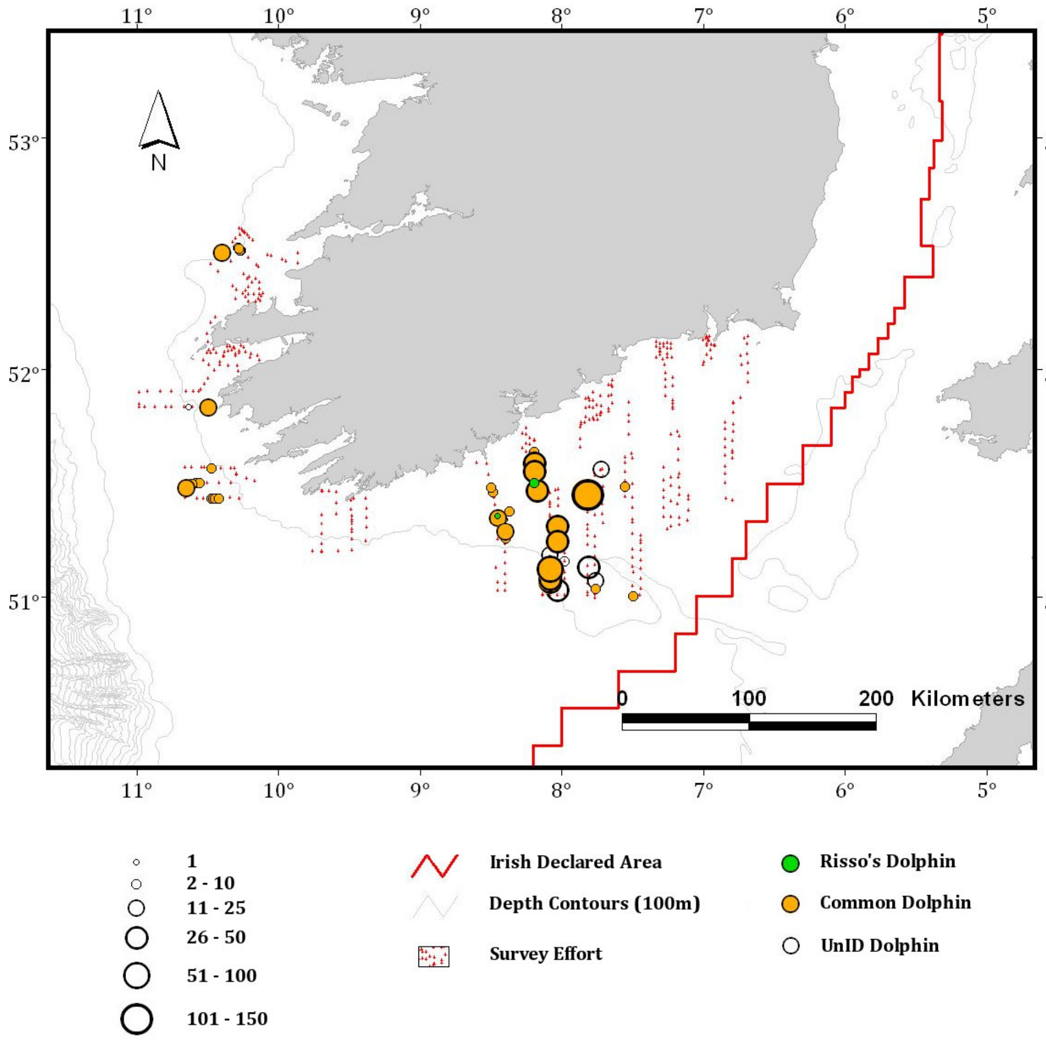

Figure 10. Distribution of dolphin and seal sightings. Celtic Sea herring acoustic survey, October 2009.

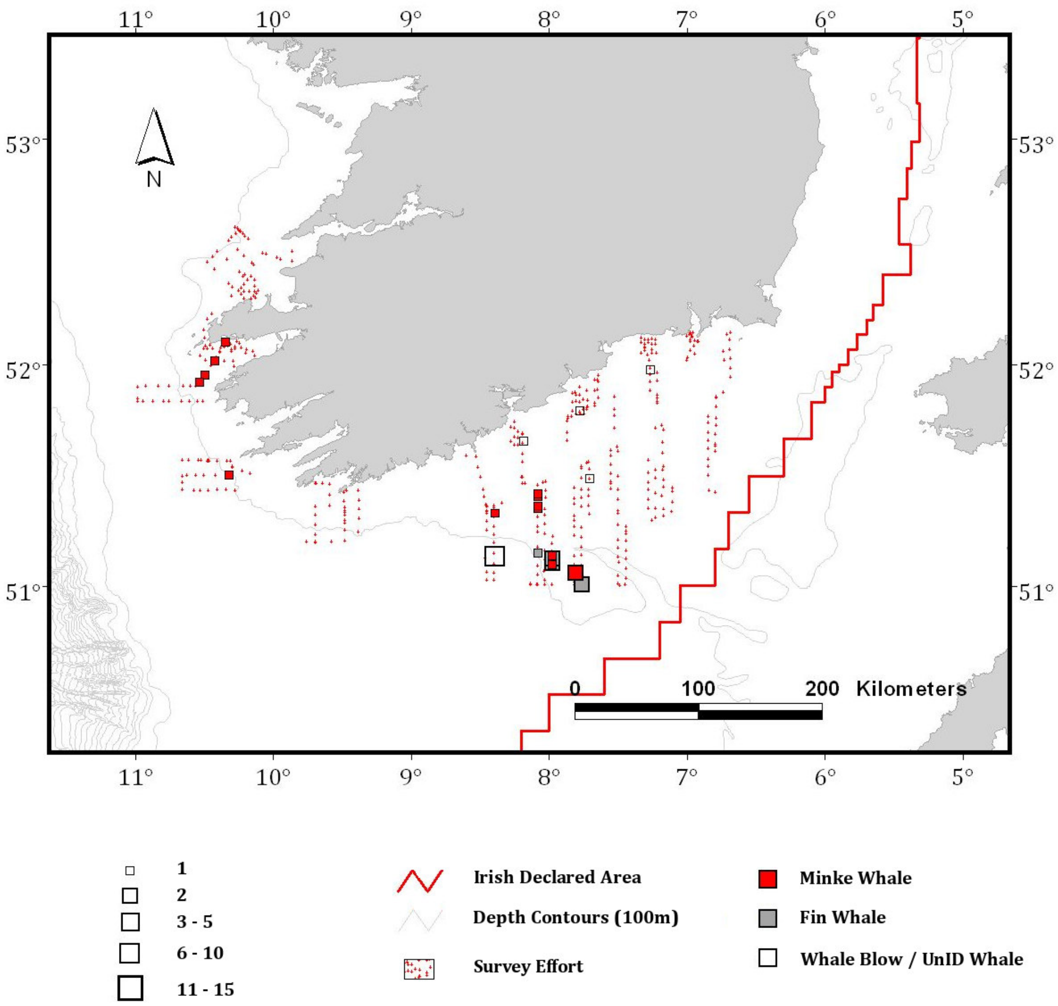

Figure 11. Distribution of whale sightings. Celtic Sea herring acoustic survey, October 2009.

October 2009	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	26
Auk Species (all)			x		x		x	x		x	x	x			x	
Fulmar	x	x	x	x	x	x	x	x	x	x		x	x	x		
Gannet	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Great Black-backed Gull		x	x	x	x	x	x			x	x	x		x	x	x
Great Shearwater	x	x	x													
Great Skua	x	x	x	x	x	x	x	x	x	x		x	x	x	x	
Guillemot	x			x	x		x		x	x		x	x	x	x	x
Herring Gull	x	x	x		x			x			x	x		x		x
Kittiwake	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Lesser Black-backed Gull	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x
Manx Shearwater	x															x
Parasitic Skua						x	x		x							
Puffin									x							
Razorbill	x	x				x			x					x		
Scoter (common)	x	x									x					
Shag		x								x	x	x		x	x	x
Sooty Shearwater	x	x	x	x		x							x			
Storm-petrel	x	x	x			x										

Figure 12. Percentage of days on which 15 bird species were recorded. Celtic Sea herring acoustic survey, October 2009.

HERRING MIDWATER TRAWL

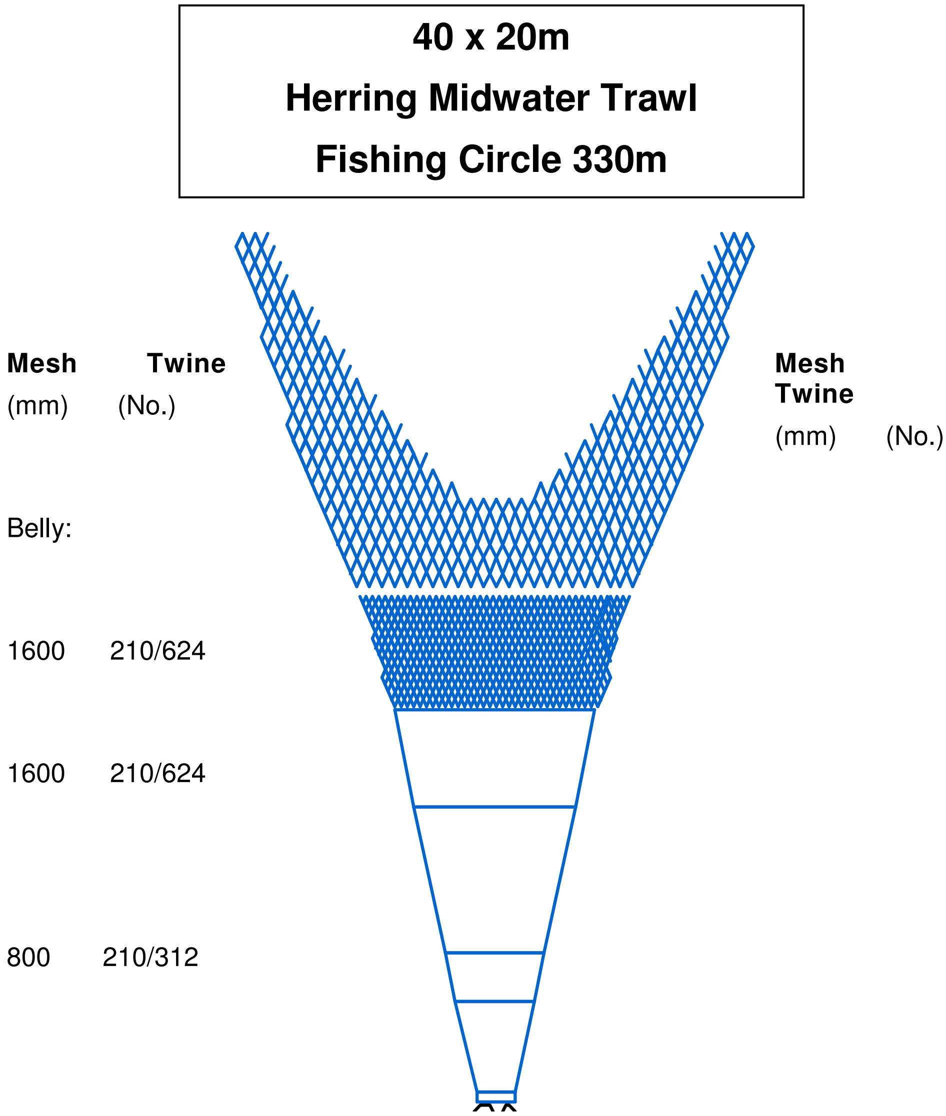

Figure 13. Single herring midwater trawl net plan and layout. Celtic Sea herring acoustic survey, October 2009.

Note: All mesh sizes given in half meshes, schematic does not show 32m brailer.

Annex 1: Calibration report

Table 1. Calibration result of the Simrad ER60 ES38B (38 KHz) split beam transducer.

Vessel :	R/V Celtic Explorer	Date :	25/10/2009
Echo sounder :	ER60 PC	Locality :	Bere Island
		TS_{Sphere}:	-33.50 dB
Type of Sphere :	WC-38,1	(Corrected for soundvelocity o	Depth(Sea floor) 30 m

Calibration Version 2.1.0.12

Comments:

Reference Target:			
TS	-33.50 dB	Min. Distance	15.00 m
TS Deviation	5 dB	Max. Distance	20.00 m
Transducer: ES38B Serial No. 30227			
Frequency	38000 Hz	Beamtype	Split
Gain	25.71	Two Way Beam Angle	-20.6 dB
Athw. Angle Sens.	21.90	Along. Angle Sens.	21.90
Athw. Beam Angle	7.01 deg	Along. Beam Angle	6.97 deg
Athw. Offset Angle	0.02 deg	Along. Offset Angl	-0.06 deg
SaCorrection	-0.63 dB	Depth	8.8 m
Transceiver: GPT 38 kHz 009072033933 1 ES38B			
Pulse Duration	1.024 ms	Sample Interval	0.191 m
Power	2000 W	Receiver Bandwidth	2.43 kHz
Sounder Type:			
ER60 Version 2.2.0			
TS Detection:			
Min. Value	-50.0 dB	Min. Spacing	100 %
Max. Beam Comp.	6.0 dB	Min. Echolength	80 %
Max. Phase Dev.	8.0	Max. Echolength	180 %
Environment:			
Absorption Coeff.	8.9 dB/km	Sound Velocity	1506.3 m/s
Beam Model results:			
Transducer Gain =	25.85 dB	SaCorrection =	-0.63 dB
Athw. Beam Angle =	6.94 deg	Along. Beam Angle =	6.90 deg
Athw. Offset Angle =	-0.03 deg	Along. Offset Angle=	-0.06 deg

Data deviation from beam model:
RMS = 0.2 dB
Max = 1.30 dB No. = 274 Athw. = -2.7 deg Along = -1.9 deg
Min = -1.18 dB No. = 319 Athw. = 1.2 deg Along = -4.8 deg

Data deviation from polynomial model:
RMS = 0.18dB
Max = 1.11 dB No. = 247 Athw. = -2.7deg Along = -1.9 deg
Min = -0.96 dB No. = 319 Athw. = 1.2 deg Along = -4.8 deg

Comments :
Flat calm conditions

Wind Force :	15 kn.	**Wind Direction :**	SW

Raw Data File: \\Expfileclstr\ER-60_Data\CSHAS_2009\RAW ER60 Files\Calibration\CE0917_calibration_

Calibration File: \\Expfileclstr\ER-60_Data\ER-60\Calibrations

Responsible : Ryan Saunders